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Neural synchronization during cooperated humming: A hyperscanning study using fNIRS

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Abstract

We examined the neural difference between cooperated face-to-face humming by simultaneously measuring two brains using a hyperscanning approach. Results showed a significant increase in the neural synchronization between two brains in the right inferior frontal cortex during a non-face-to-face humming. Thus we found the inferior frontal cortex of the right brain plays a critical role in vocal humming.

Keywords: hyperscanning, neural synchronization, humming, song, fNIRS

1. Introduction

Recently, a new technology for the measurement of the brain activity during social interaction is developed. The technology, termed *hyperscanning,* embodies the methods necessary to link two brains through two brain scanners. *Hyperscanning* allows for the performance of human behavioral experiments in which participants can interact with each other while fMRI (functional Magnetic Resonance Imaging) is acquired in synchrony with the behavioral interactions. Thus, simultaneous fMRI recording using two fMRI apparatus (two brains) during linked social interactions can be effectively done for investigation of neural timing under cooperated behavior while the problem is it imposes heavy cost to us. On the other hand, fNIRS (functional near-infrared spectroscopy) offers a cost-effective, easy-to-use, non-invasive cortical imaging technology capable of measuring brain activity in a more naturalistic environment than fMRI. fNIRS is a relatively flexible technology and to date has been successfully

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applied in several domains (Cui et al., 2011). Therefore, to avoid the difficulty for introducing two fMRI machines, we used one multi-channel fNIRS machine and shared the channels by two brains (two participants) to enable *hyperscanning* using fNIRS instead of fMRI.

Synchronized social interactions among humans are a critical issue of cognitive behavior. However, its neural substrates that underlie how people interact in synchrony with one another are unknown. Among the synchronized cooperated cognitive behavior using cooperative chorus or games, we adopted cooperative humming of a song in two participants (two brains) and tested whether either face-to-face or non-face-to-face vocal humming condition is effective for synchronized humming.

2. Methods

2.1 Apparatus

We used one NIRS apparatus and shared the channels by two brains (two participants) to enable *hyperscanning*. Thus, the present study used fNIRS-based *hyperscanning* to examine the neural features of humming within a naturalistic situation. We examined the neural difference between single and cooperated humming under face-to-face and its preventing condition (non-face-to-face condition) by wall.

We used a LabNIRS (Shimadzu Corp. Japan) system to measure the concentration changes in oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb). A single measurement patch was attached to a regular swimming cap, which was positioned on each participant's head so that frontal cortex activity could be measured. Emitters and detectors in the midline were aligned to the arc running from the nasion through Cz to the inion position (international 10/20 system). Within participant pairs, caps were examined and adjusted to ensure similarity of position resulting in a total of 68 channels covering the whole brain area (34 for each participant with 17 channels for left and right brain, respectively). The sampling frequency was 100Hz.

2.2 Subjects

We employed 28 participants (10 females, undergraduate/graduate students), thus 14 pairs (9 male pairs and 5 female pairs) participated in the experiment.

2.3 Task

Timing and timely vocal synchronization appear critical when two peoples chorus a song together. Recent information technologies have increased the speed and volume of communication, whereas opportunities for face-to-face communication have decreased significantly. Thus, it would be interesting to determine the unique neural synchronization under face-to-face humming relative to other types of humming without face-to-face condition.
Only few studies have been reported to understanding the dynamics of social interaction where two people's brains activations via cardiovascular response are simultaneously recorded using fNIRS. Furthermore, little is known about brain mechanism of vocal synchronization in two people engaging humming. We examined the neural difference between cooperated face-to-face/non-face-to-face humming by simultaneously measuring two brains using a *hyperscanning* approach. Cui et al. (2012) established that fNIRS can be used to measure brain activity simultaneously in two people engaging in nonverbal tasks, i.e., fNIRS-based *hyperscanning*.

Each experiment was consisted of 3 conditions: (1) eye-to-eye cooperated humming (pair of participant watched each eye during humming, (2) non-eye-to-eye cooperated humming (watched wall placed in between participant preventing eye watching), and (3) single humming. Each condition was separated into 6 distinct sections ordered as follows: Rest (30 s), Task (2) 100 s, Rest (30 s), Task (1) 100 s, Rest (30 s), and Task (2) 100 s (total of 290 s). Each task block consisted of 9 trials, lasting in total about 900 s in task (2) or 900 s in task (1). For example, participants rested for 30 s, then cooperated under non-eye-to-eye condition for approximately 100 s, then rested for 30 s, then cooperated under eye-to-eye condition for approximately 100 s, then rested for a final 30 s, then cooperated under non-eye-to-eye condition for approximately 100 s. Task (3) was single humming condition, thus each participant did the task alone. Overall, the order in which participants performed the tasks was randomized.

2.4 NIRS data analysis

Wavelet Transform Coherence (WTC) was applied to evaluate relationships between the NIRS signals generated by a pair of participants. WTC is a method of measuring the cross-correlation between two time series as a function of frequency and time. It enables uncovering locally phase-locked behavior that might not be discoverable with traditional time series analysis like Fourier analysis.

3. Results

We collected the raw oxy- and deoxy-Hb (hemoglobin) signals from the whole brain surface from both pair participants and calculated coherency values using WTC and NIRS-SPM analyses .The results from 14 cooperated pairs indicated a significant increase in the neural synchronization (inter-brain coherence) between two brains in the right inferior frontal cortex during a non-face-to-face humming but not during a face-to-face humming.

In a similar study, Jiang et al. (2012) examined neural synchronization during face-to-face verbal communication using fNIRS and reported a significant increase in the neural synchronization in the left inferior frontal cortex during a face-to-face dialog between partners but not during a back-to-back dialog, a face-to-face monologue, or a back-to-back monologue. Their results suggest that synchronization in the left inferior frontal cortex may due to activation of the left Broca area, which is commonly observed during verbal dialog with face-to-face communication. Interestingly, our results indicated the activation of the other side of frontal cortex (right hemisphere) where non-verbal coordination such as humming without verbal text (lyric) contributed. An active neural synchronization in humming behavior during the non-face-to-face situation suggested face-to-face eye fixation tended to disturb accurate cooperative humming by some possible reasons. One possible reason is the distraction of focal auditory attention through the eye fixation. Further study will be necessary to examine the reason why the right inferior frontal cortex plays critical role in cooperated humming.

4. Conclusion

We examined timely vocal synchronization when two peoples humming together using fNIRS-based *hyperscanning*. Results indicated a significant increase in the neural synchronization (inter-brain coherence) between two brains in the right inferior frontal cortex during a non-face-to-face humming but not during a face-to-face humming. Thus, we found that non-face-to-face humming has special neural synchronization features.

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